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MANAGING INTERNAL RADIATION CONTAMINATION FOLLOWING AN EMERGENCY: IDENTIFICATION OF GAPS AND PRIORITIES

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Abstract

Following a radiological or nuclear emergency, first responders and the public may become internally contaminated with radioactive materials, as demonstrated during the Goiânia, Chernobyl and Fukushima accidents. Timely monitoring of the affected populations for potential internal contamination, assessment of radiation dose and the provision of necessary medical treatment are required to minimize the health risks from the contamination. This paper summarizes the guidelines and tools that have been developed, and identifies the gaps and priorities for future projects.

INTRODUCTION

Capacity to respond to radiological and nuclear (RN) emergencies is included in the list of core national capacities under the International Health Regulations (IHR 2005)[(1)]. Following an RN emergency, first responders and the public may become internally contaminated with radioactive materials by breathing the contaminated air, consuming the contaminated food/water or being wounded by a sharp object/debris contaminated with radioactive materials. Timely screening for potential internal contamination, assessing the intake and radiation dose, providing necessary medical intervention and monitoring its efficacy are essential components of immediate and near-term emergency consequence management.

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WHO manages a global network called the Radiation Emergency Medical Preparedness and Assistance Network (REMPAN), designated to assist WHO in providing technical assistance to its 194 member states in the area of preparedness and response to an RN emergency[2]. At the 14th WHO REMPAN Coordination and Planning Meeting held at the University of Wurzburg, Germany, 7–9 May 2014, it was proposed and supported by the network members to set up an informal working group (WG) to address research and development issues pertaining to managing internal radiation contamination: screening for potential contamination, internal dose assessment and clinical management. The objective of this WG is to facilitate collaboration among the participating institutions of the REMPAN:

- **a.** Review the current landscape in the area of internal contamination monitoring, assessment and management, and identifying potential gaps and priority topics where further research is required and can benefit from international cooperation.
- **b.** Conduct collaborative projects to fill the knowledge and operational gaps in emergency population monitoring, internal radiation assessment and dosimetry, and medical management of internal contamination.
- **c.** Assist WHO Radiation Program and REMPAN member institutions by ensuring access to consistent, high quality technical advice on the management of internal contamination.
- **d.** Assist REMPAN collaborating centers and liaison institutions in developing their capabilities in the above mentioned technical areas.
- **e.** Mobilize joint resources for the network’s activities/meetings.

This paper first reviews the available publications and current projects relevant to managing internal radiation contamination, and then identifies potential working areas the WG may focus on in the coming years.

PUBLICATIONS AND CURRENT PROJECTS RELATED TO MANAGING INTERNAL RADIATION CONTAMINATION

There are numerous publications and tools developed to address the management of internal contamination for occupational situations or for emergency situations. Notably, the National Council on Radiation Protection and Measurement (NCRP) Report 161 and Report 166 provide a comprehensive review and guidance on managing people contaminated with radionuclides, including population monitoring, clinical decision guides and radionuclide decorporation[3, 4]. Public Health England (PHE) has developed a guidance document on screening people for internal radioactive contamination[5], practical guidelines on thyroid monitoring for radioiodine using handheld instruments[6] and a software tool for the rapid calculation of internal dose from measurements of people in an emergency[7]. In addition, the U.S. Centers for Disease Control and Prevention (CDC) is developing the Internal Contamination Assessment Tool software for screening internal contamination (early triage) using handheld instruments and portal monitors, the International Atomic Energy Agency (IAEA) is developing a guidance document on the medical management of internal contamination, while the World Health Organization (WHO) is revising its 1999 guidelines for iodine prophylaxis following nuclear accidents.

The IAEA and the International Organization for Standardization (ISO) have published methods and standards for monitoring and assessing occupational radiation exposure due to intake of radionuclides[8–15]. These methods, standards and guides provide useful information for managing internal contamination following an emergency although the methodology and approach for managing internal contamination for emergency situations are different than those for occupational situations. For emergency situations, monitoring and assessment must be carried out quickly and in a robust manner, since a potentially large population of physically diverse individuals needs to be screened and assessed in a short period of time. As a result, the dose thresholds and the required sensitivities and accuracies for the monitoring and assessment methods are less restrictive than those used for occupational situations,

Other publications, although not specifically addressing the management of internal contamination, cover the essential aspects of population monitoring and medical management following an RN emergency. These include the second edition of the Population Monitoring Guide of the U.S. CDC[16], the third edition of the Medical Aspects of Radiation Incidents published by the Radiation Emergency Assistance Centre/Training Site (REAC/TS)[17], the TMT Handbook[18], the Radiation Emergency Medical Management (REMM) online tool[19], the IAEA safety criteria for use in preparedness for and response to a nuclear or radiological emergency[20], the IAEA generic procedures for medical response during a nuclear or radiological emergency[21], the IAEA actions to protect the public in an emergency due to severe conditions at a Light Water Reactor[22] and the respective health hazard charts[23], and three publications from the International Commission on Radiological Protection (ICRP) on the principles of protecting people during an RN emergency[24–26]. These publications provide guidance on a wide range of activities including the monitoring and medical management of people who may be internally contaminated with radionuclides.

EMERGENCY POPULATION MONITORING FOR INTERNAL RADIATION CONTAMINATION

Population monitoring is an essential element of the response to an RN emergency. It starts soon after an RN emergency is reported. The key objectives of population monitoring are to

- **a.** identify individuals whose health may be in immediate danger and may need immediate medical care or decontamination,
- **b.** identify individuals who may need medical treatment for radiation exposure or contamination, further evaluation, or short-term health monitoring,
- **c.** recommend and, to the extent possible, facilitate treatments that may reduce the risk of future health consequences of radiation exposure or contamination,
- **d.** register potentially affected populations for long-term health monitoring, and

e. provide assurance to individuals who are not exposed or contaminated.

Some guidelines have been developed for population monitoring following an RN emergency[4, 16, 18]. However, this WG recognized that, although these elaborate guidelines provide detailed scientific or regulatory recommendations, practical yet short manuals are more useful to the first responders and medical personnel when they perform population monitoring. Current guidelines should be reviewed and evaluated for their applicability and limitations. Available protocols may need to be harmonized; these protocols can also be used as a basis for short manuals and check lists (no more than a few pages each). Applications for handheld devices may need to be developed with practical information that responders can use, focusing on three major areas:

a. initial sorting for highly contaminated casualties,

b. early triage for internally contaminated casualties, and

c. bioassay and dose assessment for internally contaminated individuals.

An incomplete list may include the following specific manuals:

- Screening for highly contaminated casualties using a handheld detector.
- Screening for highly contaminated casualties using a personal portal monitor.
- Early triage for internally contaminated casualties using nose blow before removing external contamination.
- Early triage for internally contaminated casualties using facial swipe or nasal swab before removing external contamination.
- Early triage for internally contaminated casualties using a portable whole-body counter (WBC) after removing external contamination.
- Early triage for internally contaminated casualties using a personal portal monitor after removing external contamination.
- Early triage for internally contaminated casualties using epidemiological data (e.g. location at the time of the incident and how much time spent there).
- Thyroid monitoring and dose assessment.
- Whole body and partial body monitoring and dose assessment (technique specific manuals).
- Urine/fecal bioassay and dose assessment (radio-nuclide specific manuals).

It should be noted that any meaningful assessment of internal contamination involves first the removal of external contamination. If initial screening shows that an individual is contaminated, removal of the outer layer of clothing and external decontamination of the individual should be performed prior to any attempt for internal contamination assessment.

Special populations (e.g. children, pregnant women, nursing mothers, the elderly, people with physical or mental disabilities, ethnic groups with cultural or linguistic barriers) need special attention when performing population monitoring, as they may be more sensitive to radiation exposure than the average population and/or require special considerations during the screening, triage, decontamination and assessment.

Experiences from both the Chernobyl and Fukushima accidents show that only robust techniques work well for population monitoring. Thus, it is necessary to evaluate, in advance, the accuracy and uncertainty of the methods and techniques to be used in response to a large-scale RN emergency. This may include a consideration of the physical characteristics of all potential subjects for direct measurements and the information required for improving dose estimations (e.g. age, sex, height, weight, behavior). To validate these robust monitoring techniques, more sophisticated measuring methods/techniques may be used for selected persons or/and groups. This WG can carefully review and discuss many lessons learned from the Fukushima accident(27) and initiate a new project to address those issues.

MONITORING AND DOSE ASSESSMENT FOR CHILDREN

Children, as one of the most vulnerable populations during an RN emergency, may have a higher risk of being contaminated by radioactive materials, receive higher doses per unit intake compared with adults, are more sensitive to radiation health effects, and may suffer more significant psychosocial impacts than adults. Thus, children should be of more concern than adults for their potential exposure to radiation during an RN emergency. Extensive individual monitoring for children was carried out in past major RN emergencies, such as the Goiânia accident(28), the Chernobyl accident(29) and the Fukushima accident(30). It has been demonstrated that monitoring large numbers of children in an emergency situation can be challenging, both from the perspective of accommodating their needs as well as adapting protocols to account for various ages and body sizes. Experiences gained and lessons learned from these three accidents are summarized, while gaps and potential tasks for this WG to address are discussed.

The Goiania accident occurred on 13 September 1987 when a shielded teletherapy unit containing over 50 TBq of ^{137}Cs was removed from its protective housing in a junk yard in Goiânia, Brazil. Fragments of the radioactive source were dispersed and many people were contaminated. The initial screening of 112 000 individuals, using survey detectors, revealed that 120 individuals were contaminated on their clothing and shoes, while another 129 were found to have both external and internal contamination(28). These 249 individuals, including many children, were further monitored through *in vitro* and *in vivo* bioassay.

The Goiânia accident resulted in experience in monitoring children for internal contamination. These include the following:

- **a.** *In vitro* bioassay for young children (aged 1–2 years old) by counting excreta (urine and feces) collected on their disposable diapers(31).
- **b.** *In vivo* bioassay for young children using whole-body counting, where a staff member stayed in the counting room when a child was counted to help the child cope with anxiety(31).

c. *In vivo* bioassay of a new born baby, where a staff member lay in the counting position with the infant held over her body(32).

d. Treating children with Prussian Blue (Radiogardase®), where children of 4–9 years old treated with 1–1.5 g d^{-1} divided into 2–3 equal doses showed an average reduction of biological half-life of 43%, while adolescents of 12–14 years old received up to 10 g d^{-1} showed an average reduction of biological half-life of 46%(31).

e. Adapting the biokinetic and dosimetric models for ^{137}Cs developed by the Oak Ridge National Laboratory (ORNL) for assessing radiation doses to the Goiânia children, as the heights and weights of Goiânia children are lower than those considered standard for the respective ORNL age groups(33).

On 26 April 1986, the most severe nuclear accident in human history occurred at Chernobyl, in the former USSR. Many members of the public in Russia, Belarus and Ukraine were exposed to the radionuclides released from this accident, including radioiodine isotopes. During the following weeks, large-scale thyroid monitoring was performed involving more than 300 000 people, including children. The activity of ^{131}I in the thyroid at the time of measurement, based on direct thyroid counting using a survey meter, was estimated for each individual. To calculate thyroid dose, it was assumed that the intake was from acute inhalation and chronic ingestion. For accurate dose assessment, it is important to identify the main intake route for each age group of the population. A technique for identifying the main intake route was developed based on the survey results(34). As young children inhale less air than adults but consume more milk and dairy products, chronic ingestion was a more important intake route for them; the activity of radioiodine in the thyroid of a child was not necessarily lower than that in the thyroid of an adult.

On 11 March 2011, the Fukushima Daiichi Nuclear Power Station was seriously damaged by the effect of gigantic tsunamis generated by the Great East Japan Earthquake, resulting in core melt-down due to the loss of cooling functions for the reactors. Significant amounts of radionuclides were released into the environment from the damaged reactors. However, the radiological impact on members of the public from the Fukushima accident is considered to be much lower than that from the Chernobyl accident thanks to timely evacuation and restrictions on food consumption(35).

The number of human measurements at the early stage of the Fukushima accident was very limited(36–39), making it difficult to reconstruct internal doses to residents in affected areas(40). The screening campaign for thyroid radiation exposure in children was performed by the local emergency headquarters in late March 2011(39). This campaign covered 1080 children aged from 0 to 15 years old. A major problem discovered during this campaign was the measurement of the thyroid using non-spectrometric counting devices, such as survey meters, under a relatively high ambient radiation background. Net activity of ^{131}I in the thyroid of each subject was obtained by subtracting the readings at the shoulder from that at the neck surface(39, 41), but this requires many considerations including the biokinetics of the incorporated radionuclides, the shielding effect on ambient radiation by the body and the counting statistics. Another problem identified during the measurement process was that the placement of a detector probe on the neck surface may lead to a significant uncertainty. The counting geometry should be standardized while the calibration of the counting device should be age dependent.

Whole-body measurements of Fukushima residents were initiated by research institutes in late June 2011 at the request of Fukushima Prefecture[42]. These measurements were performed mainly on children. However, those under 4 years old were not considered as it was difficult to measure them with WBCs; their parents (or relatives) were measured as surrogates instead. In order to avoid underestimating the internal dose from the intake of radioactive cesium (^{134}Cs and ^{137}Cs), it was assumed that the intake (acute via inhalation) occurred on March 12 when the first explosion happened at the nuclear power station. This assumption, however, might have led to a significant over estimation of the dose received for children based on the late measurements. A small residual activity (even close to the detection limits of the WBCs) often meant a large dose was estimated, as a significant fraction of radioactive cesium is cleared from the body in the first few days.

The WG on internal radiation contamination may consider initiating a project to address the above technical issues related to children monitoring and dose assessment, focusing on the important tasks, such as calibration of the measurement instruments for different age groups and implementation of age-dependent biokinetic/dosimetric models for internal dose assessment. The success of such a project would help fill a significant gap in responding to an RN emergency.

MEDICAL MANAGEMENT OF INTERNAL RADIATION CONTAMINATION

The medical consequences of an internal radiation contamination are usually described as long-term effects unless the intake is significant enough to cause short-term tissue reactions. However, medical treatment for internal contamination should be administered shortly after the contamination occurs as the efficacy of the treatment may be compromised by the delay. Therefore, following an RN emergency where internal contamination may be involved, rapid triage of the populations for potential internal contamination and efficient medical management is very important[43].

The WG on internal radiation contamination has a wide range of expertise (bioassay, dosimetry, medical management). The scientific knowledge and operational experience give this group the necessary competency to provide advice and assistance in medical management following an RN emergency. The group aims to update the recommendations on medical management of internal radiation contamination by analyzing current recommendations, identifying the knowledge and operational gaps and needs, and monitoring the progress on scientific and technological development.

Guidelines, manuals and tools on managing internal radiation contamination have been developed by national and international organizations, such as the Agence nationale de sécurité du medicament et des produits de santé (ANSM) and l'Autorité de sûreté nucléaire (ASN) in France, the Food and Drug Administration (FDA) and the National Council on Radiation Protection and Measurements (NCRP) in the US, Public Health England (PHE) in the UK, the IAEA and WHO[4, 21, 44–47]. These publications and tools exist in varied formats, provide non-consistent information for the indications of treatments and do not always offer sufficient guidance for practical use. The WG is going to review these publications and tools in detail, as done by Leiterer *et al.*[48], compile characteristics of currently recommended medical treatments, evaluate their conditions of application and limitations and identify the potential difficulties the responders/receivers may face when they perform a treatment for internal contamination which is relatively new to them. It is expected that new guidance may need to be developed with practical information for use by responders and medical personnel.

In the framework of European projects, such as the Treatment Initiatives after Radiological Accidents (TIARA)[49], previous reviews have revealed

a. disagreement on treatment decisions and protocols between countries, especially between neighboring countries where harmonization could facilitate the operational aspects of medical management following an RN emergency;

b. insufficiencies or absence in medical countermeasures for some radionuclides; and

c. the need for developing appropriate new treatments to address complex exposure situations, such as contamination of children, pregnant women or the elderly, potential contamination by a mixture of radionuclides and/or other chemicals, and potential contamination of a large number of people where medical treatments need to be timely available and easily administered.

Development of biokinetic models pertaining to medical treatment can improve the quality of intake and/or dose assessment so that better decisions on treatment or better evaluation of the treatment can be made. For example, DTPA (diethylene triamine pentaacetate, in either Ca or Zn form) has been used to increase excretion of actinides incorporated in the body. As the administration of DTPA affects the regular biokinetics of the actinides, the standard biokinetic models used to assess the intake and dose for an individual contaminated with actinides but administered with DTPA are inadequate. The European Radiation Dosimetry Group (EURADOS) is developing new biokinetic models to address this issue[50, 51]. This WG may seek future collaborations with EURADOS on this topic.

In the past years, scientists have been seeking and testing new candidate molecules that could be used to decorporate radionuclides, identifying promising decorporation indications from licensed drugs that are already on the market and developing innovative pharmaceutical forms with antidotes drugs in use in order to treat an internal contamination involving one or several radionuclides. The WG is going to further review these studies, identify the ones with significant and/or promising indications, and propose new project(s), if feasible.

NEXT STEPS

The WG on internal radiation contamination has identified the gaps in monitoring, assessment and treatments based on the existing literature and the experience gained from past accidents. The WG will further discuss the feasibility of initiating a few projects to address these gaps. It is worthwhile to note that work in risk communication during emergency response, is also being considered, with respect to messaging related to managing internal contamination. While general guidelines on risk communication during an RN emergency are already available[52], communicating the health risks from internal radiation contamination to patients as well as to responders and medical personnel may need to be specifically addressed.

References

1. World Health Organization. [accessed on December 08, 2014] International health regulations. 2005. Available at: http://www.who.int/ihr/publications/9789241596664/en/
2. Carr Z. WHO-REMPAN for global health security and strengthening preparedness and response to radiation emergencies. Health Phys. 2010; 96(6):773–778.
3. National Council on Radiation Protection and Measurements. NCRP Report 161. Bethesda, MD, USA: 2008. Management of persons contaminated with radionuclides: handbook.
4. National Council on Radiation Protection and Measurements. NCRP Report 166. Bethesda, MD, USA: 2010. Population monitoring and radionuclide decorporation following a radiological or nuclear incident.
5. Youngman, MJ., Fell, TP., Fitt, EE., Gregoratto, D., Ham, GJ., Hammond, DJ., Jones, LA., Scott, JE., Shutt, AL. HPA-CRCE-014. Health Protection Agency; Chilton, Didcot, Oxfordshire, UK: 2011. Guidance on screening people for internal radioactive contamination.
6. Youngman, MJ. HPA-CRCE-044. Health Protection Agency; Chilton, Didcot, Oxfordshire, UK: 2013. Practical guideline on thyroid monitoring for radioiodine using handheld instruments.
7. Youngman MJ, Davis KE, Etherington G, Marsh JW. ERIDAS, a computer program for rapid calculation of internal dose from measurements of people in an emergency. Radiat Prot Dosim. 2007; 127(1–4):374–377.
8. International Atomic Energy Agency (IAEA). Methods for Assessing Occupational Radiation Doses due to Intakes of Radionuclides. Vienna, Austria: IAEA; 2004.
9. International Organization for Standardization. ISO 20553. Geneva, Switzerland: 2006. Monitoring workers occupationally exposed to a risk of internal contamination with radioactive material.
10. International Organization for Standardization. ISO 27048. Geneva, Switzerland: 2010. Radiation protection—dose assessment for the monitoring of workers for internal radiation exposure.
11. International Organization for Standardization. ISO 28218. Geneva, Switzerland: 2010. Radiation protection—performance criteria for radiobioassay.
12. International Atomic Energy Agency (IAEA). Assessment of Occupational Exposure due to Intakes of Radionuclides. Vienna, Austria: IAEA; 1999.
13. International Atomic Energy Agency (IAEA). Assessment of Doses to the Public From Ingested Radionuclides. Vienna, Austria: IAEA; 1999.
14. International Atomic Energy Agency (IAEA). Indirect Methods for Assessing Intakes of Radionuclides Causing Occupational Exposure. Vienna, Austria: IAEA; 2000.
15. International Atomic Energy Agency (IAEA). Direct Methods for Measuring Radionuclides in the Human Body. Vienna, Austria: IAEA; 1996.
16. US Centres for Disease Control and Prevention. Population Monitoring in Radiation Emergencies: a Guide for State and Local Public Health Planners. 2. US CDC; Atlanta, GA, USA: 2014.
17. Radiation Emergency Assistance Center/Training Site (REAC/TS). The Medical Aspects of Radiation Incidents. 3. REAC/TS; Oak Ridge, TN, USA: 2013.
18. Rojas-Palma, C.Liland, A.Jerstad, AN.Etherington, G.Pérez, M.Rahola, T., Smith, K., editors. The TMT Handbook: Triage, Monitoring and Treatment of People Exposed to Ionising Radiation Following a Malevolent Act. Lobo Media AS; Norway: 2009. Available at http://hera.openrepository.com/hera/handle/10143/96389 [accessed on December 06, 2014]
19. REMM. [accessed on November 07, 2014] Radiation emergency medical management: initial incident activities, triage guidelines. Available at http://www.remm.nlm.gov/

20. International Atomic Energy Agency. Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency. Vienna, Austria: IAEA; 2011.
21. International Atomic Energy Agency (IAEA). Generic procedures for medical response during a nuclear or radiological emergency. Vienna, Austria: IAEA; 2005.
22. International Atomic Energy Agency (IAEA). Actions to Protect the Public in an Emergency due to Severe Conditions at a light Water Reactor. Vienna, Austria: IAEA; 2013.
23. International Atomic Energy Agency (IAEA). Placing the Radiological Health Hazard in Perspective in an Emergency due to Severe Conditions at a Light Water Reactor. Vienna, Austria: IAEA; 2013.
24. International Commission on Radiological Protection. Principles for intervention for protection of the public in a radiological emergency. ICRP Publication 63, Ann ICRP. 1992; 22(4)
25. International Commission on Radiological Protection. Protecting people against radiation exposure in the event of a radiological attack. ICRP Publication 96, Ann ICRP. 2005; 35(1)
26. International Commission on Radiological Protection. Application of the commission's recommendations for the protection of people in emergency exposure situations. ICRP Publication 109, Ann ICRP. 2009; 39(1)
27. Gonzalez A, et al. Radiological protection issues arising during and after the Fukushima nuclear reactor accident. J Radiol Prot. 2013; 33:497–571. [PubMed: 23803462]
28. International Atomic Energy Agency (IAEA). The Radiological Accident in Goiânia. Vienna, Austria: IAEA; 1988.
29. International Atomic Energy Agency (IAEA). IAEA-TECDOC-1240. Vienna, Austria: IAEA; 2001. Present and future environmental impact of the Chernobyl accident.
30. International Atomic Energy Agency (IAEA). [accessed November 18, 2014] IAEA international fact finding expert of the nuclear accident following the great east Japan earthquake and tsunami: Preliminary Summary. Jun. 2011 Available at http://www.iaea.org/newscenter/focus/fukushima/missionsummary010611.pdf
31. International Atomic Energy Agency (IAEA). IAEA-TECDOC-1009. Vienna, Austria: 1998. Dosimetric and medical aspects of the radiological accident in Goiânia in 1987.
32. Bertelli L, Oliveira CAN, Lipsztein JL, Wrenn ME. A case study of the transfer of ^{137}Cs to the human fetus and nursing infant. Radiat Prot Dosim. 1992; 41:131–136.
33. Lipsztein JL, Bertelli L, Melo DR. Application of in-vitro bioassay for ^{137}Cs during the emergency phase of the Goiânia accident. Health Phys. 1991; 60:43–50. [PubMed: 1983980]
34. Shinkarev S. The technique for identifying the main ^{131}I intake route for the populations based on results from thyroid radiometric survey after the Chernobyl accident (in Russian). Radiat Meas Instrum News (ANRI). 2008; 4:32–44.
35. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami. United Nations; New York, USA: 2014. Sources, effects and risks of ionizing radiation. Report to the General Assembly with scientific annexes, volume I, scientific annex A.
36. Tokonami S, Hosoda M, Akiba S, Sorimachi A, Kashiwakura I, Balonov M. Thyroid doses for evacuees from the Fukushima nuclear accident. Sci Rep. 2012; 2:507. [PubMed: 22792439]
37. Matsuda N, Kumagai A, Ohtsuru A, Morita N, Miura M, Yoshida M, Kudo T, Takamura N, Yamashita S. Assessment of internal exposure doses in Fukushima by a whole body counter within one month after the nuclear power plant accident. Radiat Res. 2013; 179:663–668. [PubMed: 23642080]
38. Kamada N, Saito O, Endo S, Kimura A, Shizuma K. Radiation doses among residents living 37 km northwest of the Fukushima Daiichi nuclear power plant. J Environ Radioact. 2012; 110:84–89. [PubMed: 22445876]
39. Kim, E., Kurihara, O., Suzuki, T., Matsumoto, M., Fukutsu, K., Yamada, Y., Sugiura, N., Akashi, M. Screening survey on thyroid exposure for children after the Fukushima Daiichi nuclear power station accident. Proceedings of the 1st NIRS symposium on reconstruction of early internal dose in the TEPCO Fukushima Daiichi nuclear power station accident; July 2012; Chiba, Japan: National Institute of Radiological Sciences; 2012. p. 59-66.NIRS-M-252

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40. Kurihara, O., Kim, E., Fukutsu, K., Matsumoto, M., Suh, S., Akahane, K., Sakai, K. NIRS's Project for the Reconstruction of Early Dose to Inhabitants in Fukushima After the Nuclear Disaster. In: Takahashi, editor. Radiation Monitoring and Dose Estimation of the Fukushima Nuclear Accident. Springer Open; Tokyo, Japan: 2014. p. 177-188.

41. Hosokawa Y, Hosoda M, Nakata A, Kon M, Urushizawa M, Yoshida MA. Thyroid screening survey on children after the Fukushima Daiichi nuclear power plant accident. Radiat Emerg Med. 2013; 2(1):82–86.

42. Momose, T., et al. Whole-body counting of Fukushima residents after the TEPCO Fukushima Daiichi nuclear power station accident. Proceedings of the 1st NIRS symposium on reconstruction of early internal dose in the TEPCO Fukushima Daiichi nuclear power station accident; July 2012; Chiba, Japan: National Institute of Radiological Sciences; 2012. p. 59-66.NIRS-M-252

43. International Atomic Energy Agency (IAEA). Medical Management of Patients Internally Contaminated with Radionuclides in a Radiation Emergency. Vienna, Austria: IAEA; 2015. to be published soon

44. Agence nationale de sécurité du médicament et des produits de santé (ANSM). Fiches piratox/ piratome de prise en charge thérapeutique. Paris, France: ANSM; 2010.

45. L'Autorité de sûreté nucléaire (ASN). Guide national—intervention médicale en cas d'évènement nucléaire ou radiologique. Paris, France: ASN; 2008.

46. Health Protection Agency (HPA). Advice from the Health Protection Agency. RCE 017. Chilton, Public Health England; Didcot, Oxfordshire, UK: 2010. Use of Prussian blue for decorporation of radiocaesium.

47. World Health Organization (WHO). Guidelines for Iodine Prophylaxis Following Nuclear Accidents. Geneva, Switzerland: WHO; 1999.

48. Leiterer A, Bardot I, Ménétrier F, Bardot S, Grémy O, Bérard P, Pech A, Favaro P. Medical countermeasures after a radiological event: An update from the CATO project. Int J Radiat Biol. 2014; 90(11):1043–1047. [PubMed: 24844372]

49. Ménétrier F, Berard P, Joussineau S, Stradling N, Hodgson A, List V, Morcillo MA, Paile W, Holt DCB, Eriksson T. TIARA: treatment initiatives after radiological accidents. Radiat Prot Dosim. 2007; 127(1–4):444–448.

50. Breustedt B, et al. The CONRAD approach to biokinetic modeling of DTPA decoporation therapy. Health Phys. 2010; 99(4):547–552. [PubMed: 20838097]

51. Kastl M, Giussani A, Blanchardon E, Breustedt B, Fritsch P, Hoeschen H, Lopez MA. Developing a physiologically based approach for modeling plutonium decorporation therapy with DTPA. Intl J Rad Bio. 2014; 90(11):1062–1067.

52. International Atomic Energy Agency (IAEA). Communication with the Public in a Nuclear or Radiological Emergency. Vienna, Austria: IAEA; 2012.